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AEROSPACE AND THE ENVIRONMENT

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AEROSPACE AND THE ENVIRONMENT

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INTRODUCTION

As a result of the constant pressure that environmentalists and ecologists have applied to Governments and industries during the last two decades, people are now more aware of the serious damage that industry, transport and domestic activities can cause to the environment. Such damage threatens almost every aspect of life on earth, since it affects the quality of air, water and soil. For human beings, animals and plants, pollution of the air, and of waters and soils, can result in discomfort, higher incidences of diseases and sometimes death. Pollution also has damaging effects on forests, agriculture and buildings and other structures.

It appears that some of the damage to the environment caused by pollution could be alleviated or prevented by applying local or global preventive and/or corrective measures. Some efforts in this direction have begun, but in most cases damage has reached levels that will make it extremely difficult or even inpossible to remedy or correct. Also, since most pollutants are direct by-products of processes or activities in which human beings have been involved in order to improve quality of life and health conditions, increase food supplies for the world's fast-growing population or protect themselves against natural inclemencies, disasters or potential enemies, one might ask how those standards of living, health and nutrition achieved by advanced industrialized countries are to be maintained and even improved as well as transferred to other countries, not only without causing further degradation to the environment but improving it where it has been most affected. The answer will depend, certainly, on the economic and social costs of the policies and measures required to protect the environment.

In the transport sector, some of those policies and measures may call for the introduction of new alternative fuels, new motor vehicle designs of new technologies. (Fossil fuels widely used in industry, that is, coal, petroleum and natural gas, are the dominant source of energy in the transport sector and the main cause of pollution.) However, the introduction of alternative fuels and new-technology vehicles involves many problems. First, the development of any vehicle using an alternative fuel is a long process; marketing and acceptance by consumers could be even longer. Second, apart from the important issues of development and

efficiency for any new type of engine (as compared with those same issues as related to the gasoline-powered motor, which has

benefited from over 50 years of research and advancement), cost is a decisive factor.

Experience has demonstrated that the costs involved in the production of an alternative fuel and the establishment of a distribution network, as well as the development of a pollution-free engine appropriate for such a fuel, could result in much higher transport costs. Since transport is a component in the final cost of all goods, any hastily adopted policy could rapidly lead to widespread inflation. Such factors, among others, have been major obstacles to the success of alternative-fuel vehicles, particularly the ethanol-powered automobile that was introduced in Brazil.

I. IMPACT OF THE TRANSPORT SECTOR ON THE ENVIRONMENT

All transport vehicles, land air and water, need energy and an engine to run. Apart from gasoline, there are several available sources, such as coal, alcohol, natural gas, liquefied petroleum gas and electricity, that can provide transportation energy; and the possibility exists, at least theoretically, of developing various types of engines for each of those energy sources. For land transport, however, we know that the overwhelming choice is the automobile equipped with either a gasoline-powered internal combustion engine or, to a lesser degree, a diesel engine, followed by the railway train, modern versions of which operate with electric engines. Marine and air transports continue to operate on petroleum products. One consequence of these choices is a continuous increase in pollution of the air.

The damage that transport causes to the environment occurs during various stages: fuel extraction and processing; vehicle (automobile, motorcycle, ship and airplane) construction; transport operation; transport infrastructure building and, finally, vehicle and infrastructure scrapping and disposal. At all those stages, various pollutants, odours and noises are emitted that degrade the natural environment.

Transport vehicles are also responsible for a large number of serious accidents that can all cause loss of life and permanent human disability as well as pollution of the air. Such accidents include collision of trucks; derailment of trains sometimes carrying dangerous, poisonous and/or inflammable substances; oil tanker spills; airplane crashes etc.
A number of other nuisances such as noises and discomforts are also associated with transport.

II. OVERALL IMPACT OF AEROSPACE ON THE GLOBAL ENVIRONMENT

Volume 13 of the Transport Bulletin was devoted to the environmental effects of road transport. This issue, volume 14 is an attempt within a limited space, to outline the multiplicity of effects on the natural habitat and on people, inherent in the operation and production of flying vehicles of all types.

The spectacular growth of aerospace in general and air transport in particular over the past three decades has inevitably led to a clash of demand versus perceived environmental requirements. Whereas road transport and shipping operate on a single medium i.e. land or water respectively, aviation operates on two mediums -land and atmosphere. Therefore the effects of air transport - civil and military - on the environment, are more varied and complex than would at first appear.

Aerospace impacts the environment at three levels:

a) The boundary layer up to 1 km altitude
b) The troposphere from 9 - 17 km.
c) The stratosphere up to 50 km. which covers the ozone layer.

Operating within the atmospheric bands are the airlines, military aviation, aircraft used in general aviation, touring and training, and space vehicles. Rockets, both military and civil, are launched in the boundary layer and pass through and beyond the troposphere and the stratosphere.

By far the largest and most frequent user of the atmosphere is air transport, where approximately 17,000 airliners seating 30 or more passengers operate world-wide.1/ Of these 8857 in 1990 had seating capacity from 120 to more than 350. The growth in air traffic suffered a temporary set-back due to the global recession and the effects of the Gulf crisis in 1990/91. It is inevitable, however, that demand will grow steadily from 1992 onwards.

Airbus Industrie forecasts a total world air traffic growth in passenger-kilometers of 5.5% in the period 1990-1999 and further 5.1% in the period 2000-2009. The same source estimates that by early in the next century, "total world traffic volume is expected to be twice that of today". 2/ It is further estimated that the 1990-1999 airline growth in passenger-kilometers for Latin America is projected at 6% and 5.4% for the period 2000-2009. Comparable figures for Africa are 4.8% for 1990-1999 and 4.8% for the 2000-2009 period; Middle East 5.5% and 5.2% respectively; and Asia/Pacific 8.4% and 7.2% respectively. World passenger traffic, scheduled and non-scheduled, is estimated to rise from 1767 billion passenger-kilometers in 1989, to 4971 billion passenger-kilometers in the year 2009. By far the greatest expansion in traffic growth will be in the Asia/Pacific region where, by early 21st century, Asian airlines combined will carry more traffic than those in Europe. 2/

Similar conclusions have been reached by the Boeing Company where air travel is forecast to increase at an average rate of 5.3% per year through to the year 2005, which will double the size of the market. These figures do not, however, include statistics for the Commonwealth of Independent States (CIS, formerly the USSR). Boeing foresees no CIS domestic growth until 1994 but international traffic is projected to grow 5% through 1993 and then 10% through to the end of the decade. 3/

Air cargo is also expanding at a rapid rate. Airbus Industrie reports 811 jet freighters in service in 1990 and an estimated 1420 to be in service by the year 2000. By that time the North Atlantic would have been superseded by Europe-Far East and trans-Pacific as the key cargo route.

While civil operations are the subject of considerable number of legislation and a growing inventory of restrictions, military operations are, for obvious reasons, not generally environmentally controlled. The major air forces train to a very high degree of skill and maintain high safety standards but are unable to limit flying purely to suit pollution norms. Combat aircraft are designed and built to withstand most rigorous conditions. Noise is a major factor but is obviously not subject to civil regulations. The exceptions are where low flying is restricted in order to reduce noise. Some smaller air forces, particularly in remote areas, have no regulations.

111. POLLUTANTS ARISING FROM AEROSPACE OPERATIONS/ MANUFACTURE/MAINTENANCE

Based on estimates of fuel use and assumed emission factors (see appendix, figure 1), Dr. Mark Barrett has produced the following table of global emissions from aircraft in 1988 in thousands of tonnes. 4/

	Commercial	Military	Total
Nitrogen dioxide (NO_2)	1,625	513	2,138
Carbon monoxide (CO)	271	86	356
Carbon dioxide (CO_2)	125,000	41,000	166,000
Hydrocarbons (HC)	141	44	185
Sulphur dioxide (SO_2)	406	128	534
Water (H_2O)	16,900	53,000	223,000
Soot (C)	3	1	4

Note: Emissions exclude those incurred at refineries except for carbon dioxide.

There is no doubt that the industrial sector is the major anthropogenic polluter of the world environment, while the contribution of road transport is substantial and still growing. Road transport generates over 50% of hydrocarbons and over 70% of carbon monoxide in the atmosphere. Hence, the share of air transport in global air pollution seems negligible compared to other major sources. Nevertheless, the steady rise in the size of aircraft fleets will require continued measures to reduce emissions of all types. The overall effect of nitrogen oxides (NO_x) emitted in the upper atmosphere are not yet completely understood, nor is their total influence on global warming. It is in this field that research is being directed and technology advances being proposed to reduce NO output from aircraft engines in the future.

A. Nitrogen Oxides (NO_x)

The two oxides of Nitrogen that occur in the air as pollutants are Nitrogen Oxide (NO) and Nitrogen dioxide (NO_2). A product of combustion, NO is emitted through oxidation of nitrogen in fuel which is converted to Nitrogen dioxide in the air. Aircraft emissions, generally 90-95% NO_x by volume, combine with the unsaturated hydrocarbons in sunlight to create **ozone** in the troposphere and low stratosphere. Lower level ozone has a chemical effect and absorbs radiation, thereby contributing to the **global warming effect.** Conversely, in the stratosphere, NO_x destroy high altitude ozone which is a protective absorption agent for harmful short wave radiation from the sun. Because they are not washed out by rain, NO_x at high altitude have 20-30% more effect per unit than surface emissions.

B. Carbon Monoxide (CO)

Carbon from an engine exhaust which is not fully oxidized is emitted as CO, carbon (C), or soot. Taken together, natural sources of CO account for more than 90 per cent of its average level worldwide of between 0.1 and 0.5 ppm. That global average does not apply to cities, where 95-98 per cent of carbon monoxide comes from combustion of fuel by humans. Atmospheric concentrations of 10-20 ppm are more frequent in cities, along with brief appearances of concentrations of 100 ppm in areas of heavy motor vehicle traffic; in extreme cases, high local concentrations of up to 350 ppm can be encountered for short periods.

CO is a colorless, odorless, non-irritating yet very toxic gas. Slightly lighter than air, carbon monoxide, formed by incomplete combustion of carbon or carbon compounds, can have serious detrimental effect on health and is fatal in large doses. The toxic effect is due to the fact that it interferes with oxygen absorption by red blood cells thereby restricting the supply of

oxygen by the blood to body tissues. The first symptoms of CO poisonong in healthy persons usually appear at atmospheric concentrations of some 100 ppm. High CO levels can affect the central nervous system with impairment of physical coordination, vision and judgement. Numerous studies have shown that CO can also exacerbate cardiovascular diseases and thereby cause death. Foetuses and young children are particularly vulnerable, even to critical periods of their lives. Some of the above-mentioned effects are aggravated when CO is found in conjunction with other pollutants. Its incorporation in the blood is reversible, however, and inhaling carbon-monoxide-free air can rapidly restore the blood to nornal.

C. Carbon Dioxide (CO_2)

Carbon dioxide is a natural constituent of atmospheric air. Vast stocks of carbon are stored in the soil, oceans and atmosphere and, as a result of chemical and biological processs, there is a continuous exchange of carbon, in the form of carbon dioxide, between plants and the soil and between the oceans and atmosphere. Before human interference, a natural equilibrium subsisted.

Colorless at room temperature, CO_2 is produced by the complete combustion of materials with carbon content. Although most man-made CO_2 emissions are derived from industrial burning of coal, oil and fuel, it is estimated at present that transport vehicles in general (including air but excluding farming equipment) account for 15 per cent of all carbon dioxide released into the atmosphere. In the United States, those vehicles account for almost one quarter of emitted CO_2. The figures are expected to rise as the number of vehicles grows. Aircraft engine CO_2 emissions are estimated to represent only 2% of all stationary and mobile CO_2 sources.

Carbon dioxide is totally harmless to humans and animals. However, there is concern over the threat posed by the growing quantity of atmospheric CO_2 which, combined with other gases, is responsible for retaining an increasing portion of the atmosphere's infra-red rays. (The result is a gradual warming of the climate known as the **greenhouse effect.**)

Among specialists there is now a certain consensus that if the concentration of atmospheric CO_2 doubles, a substantial increase in global temperature will occur. Recent research seems to indicate that not only is a rise in temperature already under way, but based on current trends global temperature could rise 1.5 -4.5 centigrade by the year 2025. This potential change in climate could shift global precipitation patterns, disrupt agriculture and forestry, raise sea levels and threaten coastal cities worldwide with inundation. In the face of possible warming of the

atmosphere, the carbon dioxide issue becomes one requiring urgent measures and global solutions.

D. Hydrocarbons

These are compounds consisting only of carbon and hydrogen. Like carbon monoxide, hydrocarbons are the product of incomplete fuel combustion. Hydrocarbons include methane (CH_4), benzene (C_6H_6) and toluene (C_7H_7). Unburnt fuel emitted by an aircraft engine results in hydrocarbon pollution. The interaction of hydrocarbons in sunlight with nitrogen oxides causes photochemical chain reactions that result in the formation of oxidants.

Unburnt hydrocarbons in vapor form are harmless at their prevailing atmospheric concentrations, but in high concentrations they can cause irritation to the eyes, throat and lungs, as well as coughing, sneezing and drowsiness.

No safe level of airborne benzene has been set by the World Health Organization (WHO) and there is no known safe threshold for benzene, which is carcinogenic. WHO estimates benzene concentrated exposure of 1 ug m gives lifetime leukemia risk of 4 in 1 million. Toluene has a WHO 24 hour exposure guideline of 7.5 mg m .

E. Hydrogen chloride (HCL)

Hydrogen chloride (HCL) is produced from solids in the process of rocket flights, while water (H_20), hydrogen (H_2) and NO_x are produced from solids and liquids in rocket exhaust. Chloride (CL) is an active ozone-destroyer and it is released free by chloroflurocarbons used in refrigerants and remains intact while diffused in the atmosphere. Open burning/open detonation of solid rocket motor waste is also suspect.

F. Water (H_2O)

Aero engine combustion processes produce steam which, at high altitudes, freezes to form ice crystals. These crystals pass sunlight but reflect heat back to earth thus raising the global temperature. Ice crystals also act as a chemical catalyst, causing ozone destruction although the degree of this has not yet been established.

G. Sulphur Dioxide (SO_2)

Oxidization of sulphur to sulphur dioxide takes place during kerosene fuel combustion. In global emission terms, aircraft

engines have a miniscule SO_2 effect.

H. Industrial processes

These are volatile organic compounds (VOCs),including photochemical and non-photochemical VOCs, the latter covering chlorofluro-carbons (CFCs). VOCs mainly appear in coatings, adhesives, paints and solvents. In paint stripping, for instance, methylene chloride is emitted. In electronics, a major problem of pollution is created by soldering.

I. Carbon Fibre Composites

Carbon fibre/graphite composite materials now widely used in civil and military aircraft manufacture in place of aluminum, can become highly toxic if subjected to crashes and subsequent fire. On impact, carbon fibre can break into sharp splinters. If fire ensues, they alter chemically into small particles which cause damage to unprotected skin, lungs or eyes, while vapor can affect lungs. In addition, pockets of poisonous gas can be created.

IV. OTHER EFFECTS OF AEROSPACE ON THE ENVIRONMENT

A. Noise

Noise is the most clearly recognized and outward sign of aerospace pollution. "It seems that noise will never die as one capable of stirring those who live near an airport or within earshot of arriving or departing aircraft." 5/

Aircraft noise is also a highly political subject. Noise has produced strong differences of opinion between the developed countries and some Third World countries. In contrast to the almost continuous protests in the former, some devoloping countries tend to consider noise as of little interest as has been highlighted by Mrs. Aruna Mascarenhas, Commercial Manager, Planning, of Air India, - "Aircraft noise is, quite simply, **not** a problem of public concern in Third World countries and its abatement offers **no** perceptible benefits". 6/

Equivalent Perceived Noise Level (EPNL) is the measure of the effect of noise on average human beings, taking into account the intensity or sound pressure level, frequency, tonal value and duration. The unit of EPNL is the **Equivalent Perceived Noise Decibel (EPNdB)**. Within the broadband of jet sound there are various particular features, such as intense pure tones resulting from compressor noise.

In the civil field, the main sources of noise are airports with aircraft approaching, landing and taking off. In the landing phase there is the added factor of reverse thrust, used to slow down an aircraft once on the runway. Noise made by civil supersonic aircraft is limited to the small fleet or operational Concords with British Airways and Air France. Here there is overflying noise, which can include supersonic "boom".

Military operations are more complex, particularly with high performance combat aircraft. Noisy afterburners are often used for take-off and en-route noise levels are often high, depending on altitude. For training and operational purposes, low level flying is required, often down to earth contour; wherever possible, however, this mode is being kept to sparsely populated areas. No figures are available for the number of supersonic high altitude military flights carried out. Helicopters can also be noisy, operating at low altitudes with a beat-frequency from the rotor, together with engine noise.

B. Congestion

Aerospace operations produce two types of congestion, airport and airborne. Major airports and their road approaches have become focal points for vehicle traffic with associated pollutant emissions.

Human congestion and discomfort on a large scale are caused when there are lengthy delays in aircraft departures due to weather or **air traffic control (ATC)** limitations. Air traffic difficulties such as personnel strikes, mean that clearances for take-off are limited by what the ATC system can accommodate. This, in turn, means a queue of aircraft on the taxi-way and an increase in chemical emissions. Conversely, limits on the number of aircraft able to land at a particular airport, due for instance to poor visibility, will entail incoming machines being "stacked" vertically over a holding point, circling and slowly descending until clearance is given to approach to land.

C. Accidents and Safety

As it is a man-made and controlled vehicle operating in two mediums, and subject to the laws of gravity, the aircraft is, inevitably, involved in accidents and requires maximum attention to safety. The two most critical phases of flight involved with accidents are landing and take-off, where forms of human or system error or a combination of both can be critical.

Despite the rapid rise in air traffic and continuing increase in the size of airline fleets, the accident rates for passengers on world-scheduled services are low compared to other forms of

transport. The move towards large capacity wide-body jets has meant, however, that one fatal crash can, potentially, kill many people and cause a sharp upward trend in the year's figures. By the turn of the century, wide body aircraft with a seating capacity of 650 or more passengers are expected to be in service.

International Civil Aviation Organization (ICAO) statistics for the period 1971-1990 (see appendix graph) show that fatal accidents per 100,000 landings have decreased from 0.34 in 1971 to 0.016 in 1990, while fatal accidents per 100 million aircraft-km have gone down from 0.45 to 0.15. Very serious accidents have caused peaks at certain times, the most serious being in 1972 and 1974 when numbers of passengers killed on scheduled services rose to 1208 and 1299 respectively. Again, in 1985, numbers of passengers killed rose to 1086. These figures do not include statistics for the former USSR.

Despite stringent airworthiness requirements and generally good standards of maintenance and inspection, aircraft systems on occasion do fail and systems, thought fool-proof, develop faults.

The theory that small airlines have, on average, a higher accident rate than large ones was propounded by the Lufthansa general manager, flight operations, Heino Caesar, at a Flight Safety Foundation meeting in Singapore in November 1991. His study suggested that the worst safety combination was an airline with between one and five aircraft, based in South America or Africa, operating an airfreight flight "in less well regulated airspace, under severe monetary confinements, unable to pay professionally experienced personnel, maintaining their often old aircraft at the absolute minimum and operating in hostile weather and topography." 7/

The same Lufthansa report states that, in the 1980's, 75%of aircraft losses were due to aircrew, 13% to technical systems and 12% to the working environment. For 1990 the figures were 61%, 22% and 17% respectively.

Certain types of aircraft have proved more accident prone than others and have required a great deal of checking and modification. A particular instance is the Soviet Tupolev Tu-154 which, in the period since 1972, has been involved in 19 major accidents, causing 888 deaths. This represented one third of the total fatalities on Aeroflot flights for the period. Over the past ten years 444 Tu-154 accidents were recorded, including 5 fatal ones, raising the accident rate to 1.28 per 100,000 flight hours - far above the ICAO world rate. Landing gear and engine failures accounted for the majority of the incidents. 8/

As aircraft get older they require stricter monitoring and often require extensive refurbishing and/or re-engining to meet economic and environmental requirements.

D. Terrorism

Attempts to destroy airliners, with their passengers, in flight has become an all too common practice of political activists of many persuasions. Probably the worst example of a bomb being placed on an airliner was the explosion on the Boeing 747 operating Pan American Flight 103 over the town of Lockerbie in Scotland on December 21, 1988. The death toll on the aircraft was 259 passengers and crew. On the ground there was widespread damage and a further 11 people died. Thus the environment was extensively affected. This sort of occurrence cannot be discounted virtually anywhere in future and it involves very great effort and investment to give any assurance that it can be prevented. Security measures, unfortunately, vary markedly from one world area to another and from one country to another. Such measures are airport design, standards of surveillance and quality of trained personnel, standards of search and X-ray machinery used, plus security of baggage handling and tarmac security.

E. Falling debris

With aircraft there is a danger of metal parts or ice dropping to earth. Some of these are potentially lethal, while structural damage to buildings can and sometimes does occur.

The UK Civil Aviation Authority reports 422 falling objects logged for the period 1976-1991 during which time there were 3,255,000 aircraft movements recorded. The largest object was a 7 ft.-long section from a Boeing 747 wingflap. Some 214 of the recorded incidents involved ice, with lumps up to 20 lb. in weight. The ice comes either from break-away on the aircraft skin or from faulty galleys or toilets.

V. COMBATTING AEROSPACE POLLUTION AND OTHER ENVIRONMENTAL PROBLEMS

A. Effluents

The reduction of chemical pollutants in the atmosphere resulting from aircraft operations rests to a great extent on aero engine manufacturers. In the boundary layer, emission levels can be reduced by application of the standard ICAO landing and take-off cycle as follows:-

Operating conditions	thrust level	time (min)
taxi out	7% max	19
take-off	max	0.7
climb	85% max	2.2
approach	30% max	4.0
taxi in	7% max	7.0

Based on these criteria, unburned hydrocarbon (UHC), CO and NO_x have been reduced by about 80, 60 and 12 per cent respectively since operations in the early 1970s. HC and CO reductions have resulted in higher compression or pressure ratios and higher turbine exit temperatures. NO_x emissions have been adversely affected by these changes, although lower fuel consumption has helped improve them.2/ At idle, where UHC and CO rates are highest, combustion efficiency has improved from near 90% in the 1950s to just over 99% in the 1980s.

Where NO_x is concerned, a European Community study conducted by the UK Harwell-based Atomic Energy Authority Environment and Energy concludes that current emissions from aircraft may have increased total tropospheric ozone by about 1% and concentrations between altitudes of 9753 m to 11887 m at northern latitudes by about 5%.

There have been some dire forecasts of the effect on aerospace of global warming during the next decade or two but none of them have been backed up by proven facts and figures.

A more rational approach has been summarized by Mr. T. Metcalfe of Rolls-Royce:-

> "It has been estimated that based on an annual growth of NO_x emissions of 5%, one would see about a $0.01^{0}C$ increase in temperature in the decade - and that is assuming no improvement in NO_x technology. We need to understand the effects in much more detail - further research is desperately required to improve our understanding in a number of areas and we certainly need to know more about the contribution of ozone to global warming before any conclusions can be drawn".

Ultimately, accurate and comprehensive atmospheric measurements, at varying altitudes, latitudes and longitudes, will become available from the monitoring program being undertaken by the **US Upper Atmosphere Research Satellite (UARS)** put into orbit in 1991 from the Shuttle Discovery. Three other research aircraft will also contribute to the program.

It has been proven that high pressure ratios increase NO_x production, while reducing fuel consumption and thus CO_2 and H_2O output. All three largest aero engine manufacturers are therefore working on a future combustor design intended to reduce NO_x emissions. This design is in two stages. First, a pilot region alone is fuelled for ignition (light off) and idle power. This stage is optimized to reduce UHC and CO. At the second stage the main combustor is fuelled as well, which is optimized to reduce NO_x . Apart from the new combustor designs a more complex fuel system will be required. In the mid-1990s this technology should yield a 30% NO_x reduction. To achieve reductions of 55-70%, a technology breakthrough will be needed, which is unlikely in this decade and is deemed unnecessary by industry, if only on the basis of reliability. The costs involved will have to be very considerable.

Study work continues on the NASA **High Speed Civil Transport (HSCT)** but, here again, major technology advances will be required to meet any future ozone depletion regulations and noise requirements associated with a supersonic aircraft.

Turboprop and piston-engined aircraft generally fly over shorter distances and cruise at lower altitudes than large, longer range jet aircraft. The emissions, therefore, at lower levels tend to be washed out by the weather, with a small contribution to acid rain. Modern turboprops tend to show improved fuel consumption which leads to an increase in NO_x compared to their predecessors but there have been substantial reductions in CO and UHC. For instance, British Aerospace claims a 63% reduction in total emissions per passenger/km for its Advanced Turboprop Aircraft compared with the earlier BAe 748. There is limited scope for future improvements.

B. Convention on International Civil Aviation

In 1971, pursuant to the provisions of Article 37 of the Convention on International Civil Aviation (Chicago, 1944), International Standards and Recommended Practices for Environmental Protection were adopted and designated as Annex 16 to the Convention. Volume I was devoted to Aircraft Noise. In 1981 The International Civil Aviation Organisation (ICAO) issuedAnnex 16, Vol II on Aircraft Engine Emissions covering HC, CO,NO_x and smoke. This, however, was largely intended to coverthe boundary layer and airport environment; overall parameters for global use must await

the establishment of research criteria as mentioned earlier. National laws and regulations often differ from the requirements of Annex 16. By October 1990 over 130 states had not indicated to ICAO whether or not their national regulations and practices differed from Annex 16. Several replied that their national laws and regulations had no provisions to meet Annex 16, while Malawi stated that "due to the fact that engine emissions are not considered a significant problem, the provisions of Annex 16, Vol II, have not been incorporated in the National Regulations of Malawi, nor have the practices contained within Annex 16 been implemented in part or totally." 11/ It is clear that there is a long way to go before there is any sort of overall adoption of Annex 16 world-wide. In the meantime, ICAO's Committee on Aviation Environment Protection has recommended even stronger NO_x emission standards for future engines.

Measurement and research done at a number of airports in the USA and Europe suggest that the main emission culprits are airport facilities (e.g. power stations and car parks), not aircraft. At Gatwick Airport, studies in 1990 showed NO_x emissions in the vicinity of the terminal represented only one fifth of the total. Effects on local communities vary, depending on the distance from city center.

Following the agreements by the United Nations Economic Commission of Europe (ECE) in 1998, 22 European countries decided to freeze their NO_x at the 1987 level. Sweden implemented this by introducing a tax on aircraft exhaust emissions, although this applies only to domestic traffic. The charges are based on aircraft engine emission data, fuel consumption and airline flight procedure information. 12/ Sweden is also proposing the introduction of environmentally adjusted landing fees for both domestic and international traffic. Whether this will become internationally acceptable or not remains to be seen and there would undoubtedly be cases where airlines would re-route to avoid increased fees. Meanwhile, the ECE is also formulating a system for charges.

There is a decision, in principle, by the Swedish authorities to limit carbon dioxide and nitric oxide emissions from all sources, including road traffic to and from Stockholm-Arlanda airport to 1990 levels. Quantitative measurement of road sources and enforcement of any regulations in this respect will be very difficult. A new electric railway from Stockholm to the airport has been demanded, but, will cars be banned from the airport and will the vehicle owners agree?

C. Maintenance and Manufacture

In the developed nations regulations on toxic processes and toxic waste have been greatly extended and enforced, such as those laid down by the US Environmental Protection Agency, although this cannot be said for large sections of the Third World.

At major airports there is control of fuel spillage, aircraft de-icing fluid, etc., and avoidance of seepage into the normal drains has markedly improved. Since the 1970s, for instance, KLM at Schipol Airport has employed decontamination systems, recycled waste water and has now supplemented these with a water purification plant.

Removing old paint from aircraft and re-painting involves extensive use of chemical agents. Some 2.5 tonnes of agents are required to strip an A300 and over a tonne of paint to respray the fuselage alone. A number of airlines are now separating paint stripping and painting functions to different shops. To reduce the toxic effects of paint stripping, Lufthansa has developed a process called "aquastripping", using high pressure water streams to peel paint off. The water is recycled and paint particles removed. It is estimated that chlorinated hydrocarbon emissions at the airline's Hamburg base could thus be reduced by 90 per cent compared to 1987 levels. 13/ Also, to avoid the use of methylene chloride and phenol-based paint removers, companies such as Brent are marketing biodegradable solvent paint softeners used in conjunction with mechanical blasting.

For runway de-icing, a replacement for propylene glycol and urea has been produced by British Petroleum. Known as **Clearway 1**, it is a potassium acetate based liquid deicer which is non-toxic and, unlike glycol, does not pollute the surrounding countryside. Clearway 1 is used by British Airports Authority, the US Air Force, Germany and Scandinavia.

Manufacturing industry, particularly in developed countries, is also being forced to adhere to new rules over toxic compounds and processes. Eventual elimination is foreseen for over 180 chemicals listed in the US **Clean Air Act** and both military and civil industries are effected. Solvent and adhesive alternatives are now being developed but this involves considerable time and expenditure.

A full and economical solution to the problem of disposing of solid rocket propellants and associated contaminated waste has yet to be found. As previously stated, the present methods are open burning or detonation.

VI. DEALING WITH OTHER EFFECTS

A. Noise

Following the adoption of Annex 16 Vol I, Aircraft Noise, to the Convention on International Civil Aviation, international noise rules have now evolved to a stage where airlines face the biggest environmentally-driven re-equipment/modification program ever.

For the purposes of noise certification, old, noisy, narrow body aircraft are classified by ICAO as stage 2 aircraft under the stipulations of Annex 16 Vol I Chapter 2, while quieter modern aircraft meeting the latest requirements are classified as stage 3 aircraft under Chapter 3. This chapter demands the following limits in EPNdB: lateral 94.9, fly-over 89.0 and approach 98.8.

ICAO's noise resolution calls for States to start phasing out stage 2 aircraft from 1st April 1995 and to complete the withdrawal from service by 31st March 2002. Prior to 31st March 2002 aircraft are guaranteed 25 years service following the first issue of a certificate of airworthiness. There will be no immediate effect after 1st April 1995 on wide bodied aircraft and others equipped with high bypass ratio engines. It has also been proposed that no more than 10% of a fleet per year should be retired in any one year to assist charter and now start-up airlines. A three-year exemption will be allowed if orders or purchases to upgrade are contracted for.

The ICAO rule is advisory and it is left open to member nations as to what action they take. The United States, through the Federal Aviation Authority has put out a **Notice of Proposed Rule Making (NPRM)** on noise which differs from that of ICAO. This calls for 25% of Stage 2 aircraft to be modified or phased out by end of 1994; 50% by end of 1996, 75% by end of 1998 and 100% by end of the year 2000 - two years earlier than the ICAO requirement. Exemptions can be obtained if fleets are 85% compliant by 1st July 1999 and valid plans exist to complete Stage 2 phase-out by 31st December 2003. Unlike the ICAO rules, wide-bodied aircraft and those with high by-pass ratio engines will not be exempt. Foreign airlines operation into the USA will also have to comply. The supersonic Concord will be exempt.

The United States scene is further bedeviled by various forms of proposed State and local legislation which would speed up the process of removing Stage 2 aircraft. In the face of this, airlines are demanding that regulation should only be at a national level. This, however, involves noise damage liability. Already there are long lists of local lawsuits in the USA involving very large sums of money. Airports will ultimately have to recover these amounts from increased airline charges. Owing to lawsuits, new airport building has been at a standstill. In the US and

Europe some 19 million people live in the 95 PNdB contour around airports. By operating only Stage 3 aircraft, the number of people affected by the 95 PNdB contour could be reduced by a factor of 24.

Nearly half the world's air fleet is currently operating with stage 2 aircraft, although the largest percentage is in North America. Airbus Industrie estimates that over the period 1990 - 2008 the rest of the world (omitting North America and Europe) will have to replace 1851 aircraft for age/non environmentally acceptable reasons. Of these, the two major replacement areas are Latin America and Africa.

Propeller-driven aircraft over 5700 kg weight of various ages are also subject to a series of noise level requirements, ultimately leading to the same lateral, fly-over and approach requirements as for Stage 3 subsonic jets. Noise level rules have also been laid down for civil helicopters but Recommended Practices have not yet been developed for propeller-driven STOL aircraft. Military helicopters are, of course, not subject to civil rules. Military requirements for low noise under operational conditions are, however, leading to improved general noise levels.

Reverting to Stage 3 noise levels for subsonic transports, the world airline industry faces three choices - buying new equipment, re-engining Stage 2 aircraft or fitting Stage 2 aircraft with hush-kits. The leading international airlines are engaged in massive re-equipment and up-date programs which will allow them to meet Stage 3 standards. Other airlines, particularly those in the Third World, will not be so well placed. The ageing aircraft problem will have to be met and this will involve airframe life and condition. Future life expectancy with major modifications will have to be set against cost. Versions of the DC-9, 727 and 737 with JT8D engines will be particularly involved, as will F-28s and BAe 111s with Spey power plants and 707s/720s with JT3 engines.

Apart from any structural up-dating, the cost of hush-kitting, say a 727, will run out at about $1 million per engine. Hush-kits can bring Stage 2 aircraft up to Stage 3, although a fuel consumption penalty is involved and thus an increase in toxic emissions. Re-engining will fully meet Stage 3 requirements but it is a great deal more expensive. There are already a large number of older jets available for sale. A proportion of these will be sold on to airlines in countries unwilling or unable to enforce Stage 3 noise regulations or converted into cheap freighters. In either event they will remain noisy and "dirty".

Of the world commercial airliner fleets, 2050 aircraft are over 20 years old, of which two-thirds are in the USA. Asian airlines have the youngest fleets while Africa and Latin America have the oldest. Nearly half the world's commercial airliners are Stage 2 and more than half of these are operated by US carriers. 3/

B. Congestion

Congestion in aerospace occurs a) at and around airports and b) in the air. The growth of air traffic over the next decade will result in ever increasing congestion at many airports and limitations on the frequency of aircraft movements. Apart from the creation of entirely new airports, the demand will be for more and larger terminals, expanded associated facilities- including vehicle parking - and in a number of cases, additional runways. In Europe alone some 22 major airports will become frequency-limited by the year 2000. To a certain extent the greater use of large, high-capacity, wide-bodied jets will help but this also means many more people inbound and outbound having to use the terminal facilities simultaneously, which puts added strain on the system.

Travellers are very often possessed of dual personality. On one hand, they may be very environmentally-minded and totally against airport expansion of any kind. On the other, they are ordinary airline passengers who will complain bitterly if the airport is crowded, if they cannot obtain a flight at exactly the time they want and if it is then late. Suggestions have been made that there should be limitations on the development of certain holiday destinations and future tourist centers with associated flight restrictions. This whole concept is, of course, unworkable, bearing in mind the basic rights of travellers and the economies of the countries involved where tourism is usually a key foreign currency earner and source of employment. To separate out different types of air travel, there are moves in several countries to transfer general aviation and commuter aircraft to secondary airfields.

One environmentally sound alternative to certain aspects of an overcrowded airways system is the high speed train. Where time is the key element, however, there will be a limit to the sector lengths where railways can take over from airlines and road traffic. The proposed North European high speed rail network, together with the Channel Tunnel, could ease problems on a region of dense air traffic. In order to achieve a network (within the area bounded by Paris, London, Amsterdam, the Ruhr and Frankfurt) for the year 2000, common government transport policies and complete standardization of tracks and systems must be agreed upon. In various parts of the world, e.g. China, Africa and South America, there appears to be no practical or economic basis for the substitution of rail for air travel.

Rail travel to and from city center to airport is a logical, environmentally sound and economic method of relieving road congestion and reducing the number of vehicles operating into and parking at airports. As in the case of Arlanda in Sweden, rail links may in future be insisted upon by the authorities when a new airport or major airport expansion is being considered. British Airports Authority already has rail or underground links to its

three London Airports.

C. Air Traffic Control Systems

In the air congestion causes delays, increases in toxic emissions and is a potential source of accidents. **Air traffic control (ATC)** is the core of this problem. There is a need for overall supranational planning and control and a reduction in the number of national ATC systems compared with the USA, where there is one integrated ATC system. Technology standards for ATC equipment and navigation systems need to be standardized.

In Europe, optimum flight level in very many cases is not allocated uniformly by the air traffic controller since each pilot's request for optimum flight level is based on his own operation parameters. This results in greater fuel consumption, more cost and more pollution. Short-haul and regional services tend to be allocated to lower altitudes than medium range and long-haul flights, thereby allowing them only the minimum time on the economical cruise phase. "In general, about 50% of all flights in Europe operate at off-optimum flight levels." 2/ It is suggested that if an integrated modern ATC system was available, some 50% more flights could be handled compared to present numbers. To this end 22 nations of the **European Civil Aviation Conference (ECAC)** in 1990 committed themselves to integrating their ATC systems. To achieve this, however, may take until well into the next century.

To achieve closer lateral and vertical separation limits in controlled airspace with safety, new means of navigation and position fixing will have to become standard. The answer lies in space satellite networks for navigation, surveillance and communications with ground-based systems as the monitor. The US **Global Positioning System (GPS)** and the **Soviet Global Navigation Satellite System (GLONASS)**, both military networks, have been released for civil use- GPS free of charge for 10 years and GLONASS for 15 years.

Beyond this, ICAO has agreed to the aims of its special committee on **Future Air Navigation Systems (FANS)** which has a plan for automatic dependent surveillance (ADS). This will allow air traffic management services to be provided round the globe, including communications. To fulfil those requirements, a civil global navigation satellite system (GNSS) will have to be launched into orbit.

The final element in the congestion/safe-flying equation is to ensure that aircraft can land regularly in all levels of visibility. This involves radar cover and a very accurate landing system. Currently the ground-based **Instrument Landing System (ILS)** is used but there is wide divergence round the world in the capacity, performance and reliability of these. The minimum

standard is Category I, which gives minimum **runway visual range (RVR)** of between 1800 ft. and 3 miles. Beyond this, with progressively lower RVR, are Category II and Category III ILS, the latter usually associated with autolandings. In the USA, out of 800 airports, some 689 are equipped only to Category I standard and only 39 to Category II.

The US and other Western countries are introducing a far more accurate system called the **microwave landing system (MLS)**. This program is expensive and has suffered long delays. Just when it will become standard in the Third World is a matter of conjecture.

An alternative to MLS is now being offered, which will be independent of ground based aids. This is the **enhanced visual system (EVS)** on the aircraft itself, employing **forward looking infra-red (FLIR)** presented on a cockpit **head-up display (HUD)**. EVS is derived from well proven military equipment and trials are going on to define it's limits in fog and low cloud.

D. Accidents and Safety

With the increasing numbers of civil aircraft operating world-wide, the recognized airworthiness authorities are keeping a close watch on ageing airframes and the number of cycles they have operated. A complete cycle consists of start-up, taxi, take-off, climb, cruise, descent, landing, thrust reverse and shut-down. Factors influencing an aircraft's condition include age, type of technology and design details, number of flight hours, operating environment, maintenance, history, damage/corrosion and repair history. Each aircraft is, therefore, different. The condition of older aircraft varies greatly, often, in the Third World, depending on the efficiency and alertness, or otherwise, of the local airworthiness authority. The latest generation of airframes feature greater use of higher strength materials with better corrosion proofing. Centralized onboard digital maintenance systems provide fault recording and analysis. These will subsequently be relayed to a ground station for remedial preparations.

High ground still presents serious problems for aircraft, particularly on the approach to difficult airports. An example of this occurred in January when an Airbus A320 hit a mountain while approaching Strasburg Airport. The crash killed 87 people and the cause, at the time of writing, was under investigation. This event highlights the need for the efficacy and availability of **ground proximity warning systems (GPWS)** on aircraft - the A320 in question was not equipped with this system.

Although aircraft accidents remain low compared to passengers carried and miles flown, accidents continue to occur with aircraft in areas which were believed to be fairly foolproof. Examples of

this occurred in a series of accidents involving DC9 and MD-80 aircraft with regard to wing icing. The fatal crash of a Ryan International DC-9 in February 1991 was attributed to the failure of the aircrew to detect and remove wing ice. Icing was also suspected in the case of the crash of an SAS MD-81 where wing ice was reported to have been sucked into the aircraft's rear mounted engines on take-off.

E. Terrorism

To combat the effects of terrorism on aerospace, it will be necessary to have a major security up-grading at many airports. The requirements are for adequate means to detect weapons carried onto aircraft for hi-jacking as well as explosives smuggled on board to destroy aircraft.

Wider use of sophisticated X-ray equipment and other detection aids will be necessary in addition to the use of well-trained security personnel. Future airport designs will have to take into consideration totally separated incoming and outgoing passenger flows and X-ray of all outgoing baggage in conjunction with data processing equipment. Some western airports have already gone far in this respect but it has proved to be a costly process.

One possibility for combatting terrorism involves the aircraft themselves and not the ground environment. Using special materials developed for military armored vehicles, it is also now feasible to line baggage/cargo holds with lightweight energy absorbent materials and provide a form of "valve" which would allow the controlled escape of blast effects without wrecking the basic aircraft structure and systems.

VII. THE ENVIRONMENT AND THE THIRD WORLD

The attitude of Third World countries to questions of aerospace environment vary considerably depending on the environmental situation, the budget and whether or not the main airports are international gateways.

A. Pollutants

The stringent regulations now introduced on jet engine emissions ensure that all the main international airlines have acquired, or are in the process of acquiring, modern aircraft which conform to standards - if they are to operate into developed countries where regulations are applied. It is on the shorter ranges, where older aircraft continue to operate, that problems remain. This involves internal flights and those between countries which do not have the necessary legislation in place or are

unwilling to enforce it. Continued monitoring of this situation will be necessary. It would also assist if there were international arrangements made for sponsored finance of new equipment by banks and leasing houses.

The question of noise is more difficult as it is not recognized by many countries as a direct pollutant, particularly where there are other, much more pressing, environmental requirements. It is important to provide educational material from the school stage upwards to make communities aware of the effects of noise pollution. Installation of approved noise-measuring equipment should also be encouraged.

IATA also points out that efforts to combat noise by introducing new quiet aircraft are nullified by residential development being permitted closer to airports as noise is reduced. Examples of this exist at some airports in India where there are slums within 100 meters of the runway. The ground effluents from these slums attract birds which cause ingestion damage to aircraft. Discussions and agreements are required world-wide to introduce national legislation covering this aspect.

On the ground there is a need for an educational program aimed at airport users on the dangers inherent in toxic processes. Involved are fuel and chemical spill, drainage, recycling of waste materials, industrial processes such as plating and painting/re-painting of aircraft. Provision of re-usable catering equipment should also be encouraged.

At airports there is a need to re-assess the volume of road traffic and its emissions and, where possible, to substitute electrically-powered for petrol-powered service vehicles.

B. Air Safety

There is a continuing need to monitor air safety and maintenance standards, particularly in remote areas and areas of severe climatic conditions. Airport improvement should also have high priority with a steady program of modernization of ground based aids, including landing systems. India, for instance, is embarking on a long-awaited airport up-date program.

C. Air Traffic Control

Continued efforts must be made to improve on route communications and navigation facilities in various parts of the world. Much outdated and unreliable equipment needs replacing. There still remains actual gaps in regional communications network.

D. Security

Many Third World countries do not have a good level of security for baggage and passenger checking. There is the need for an educational program, training and provision of up-to-date X-ray equipment.

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FIG. 1

Aviation Fuel Use (1988)

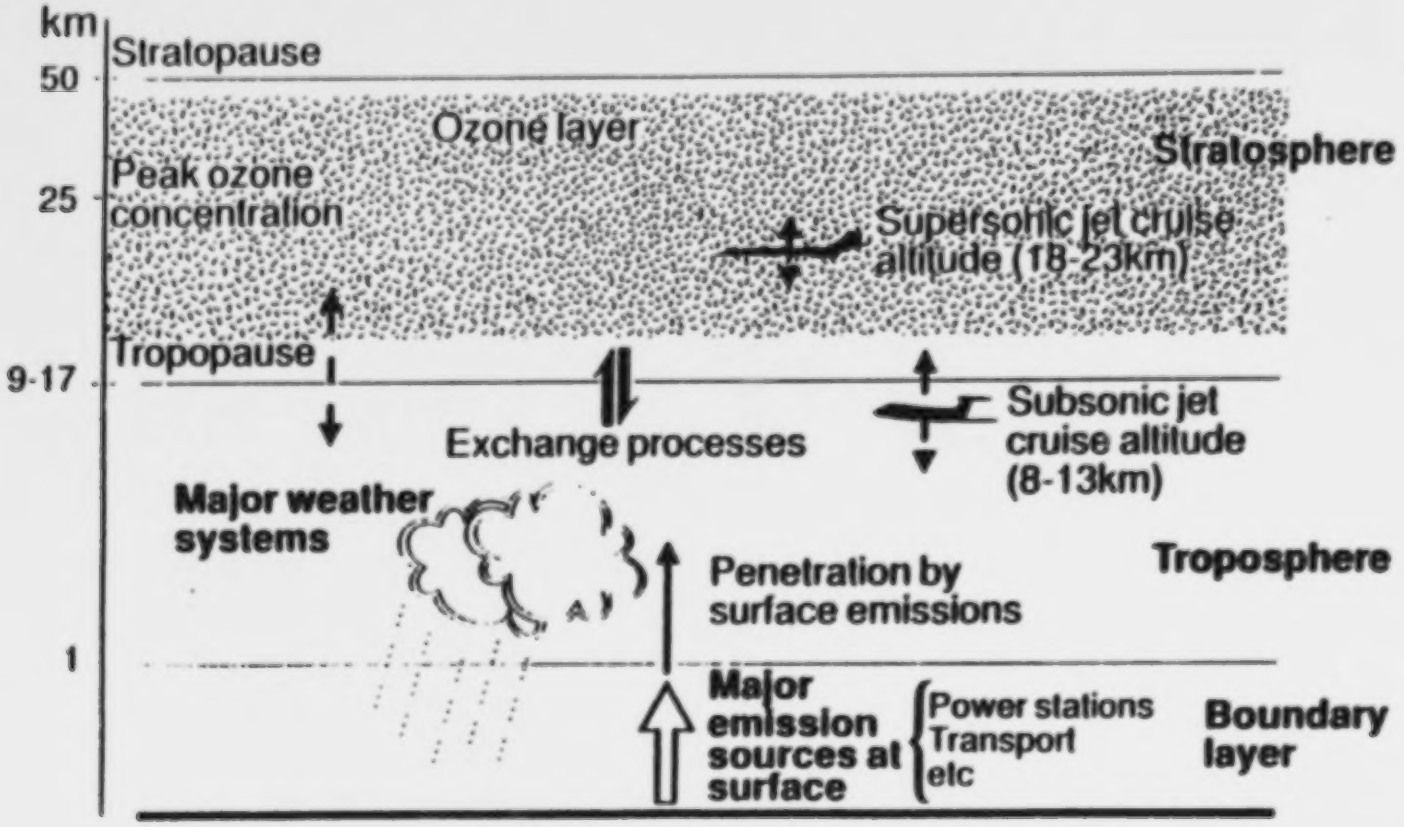
		Fuel Mt	Energy PJ	Carbon Mt	Carbon % World Total
PRODUCTION					
WORLD (Excluding USSR & E Europe)					
Avgas		2.5	118	2.1	0.0%
Wide cut jet fuel		10.0	472	8.6	0.1%
Kerosene		130.0	6,134	111.5	1.9%
TOTAL		142.5	6,724	122.0	2.0%
USSR & E EUROPE					
Assume 20% of world production					
TOTAL		35.6	1,681	31.0	0.5%
WORLD TOTAL	In aircraft	178.1	8,405	153.0	2.5%
	5% refinery losses	9.4	442	8.0	0.1%
	TOTAL	187.5	8,847	161.0	2.7%
CONSUMPTION					
Assume commercial 76% of total					
Commercial	In aircraft	135.4	6,388	116.0	1.9%
	incl. refinery losses	142.5	6,724	122.0	2.0%
Military	In aircraft	42.8	2,017	37.0	0.6%
	incl. refinery losses	45.0	2,123	39.0	0.6%
TOTAL	In aircraft	178.1	8,405	153.0	2.5%
	incl. refinery losses	187.5	8,847	161.0	2.7%

Source: UN (1990), Jenkin (1988), Renner (1991), author's assumptions.

Basic Source: Aircraft Pollution

FIG. 2

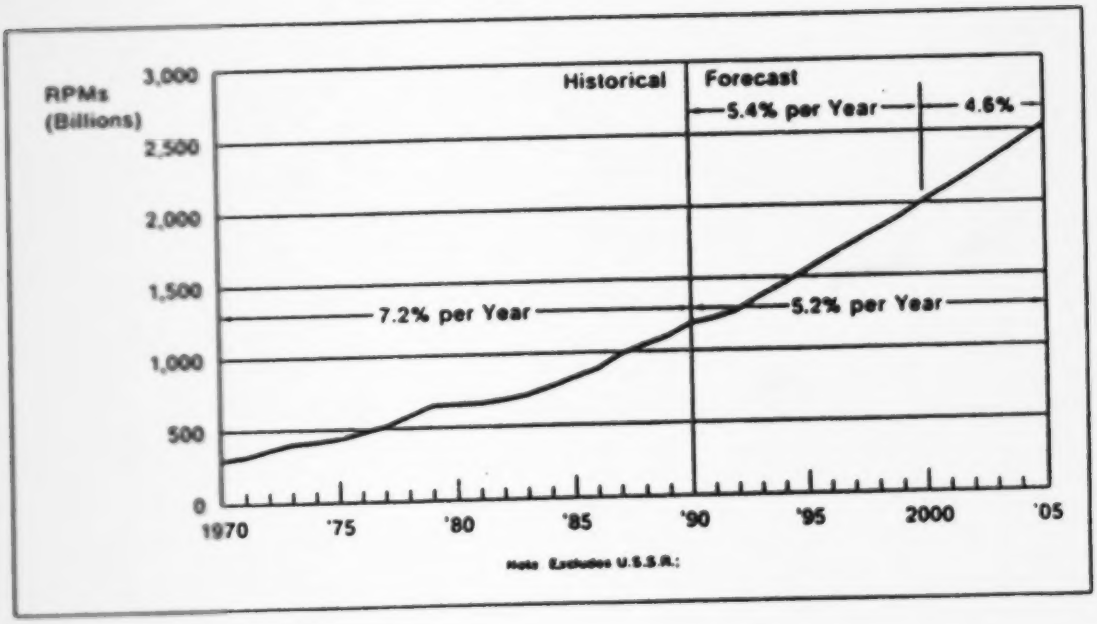
The atmosphere and emissions



SOURCE: ROLLS-ROYCE

FIG. 3

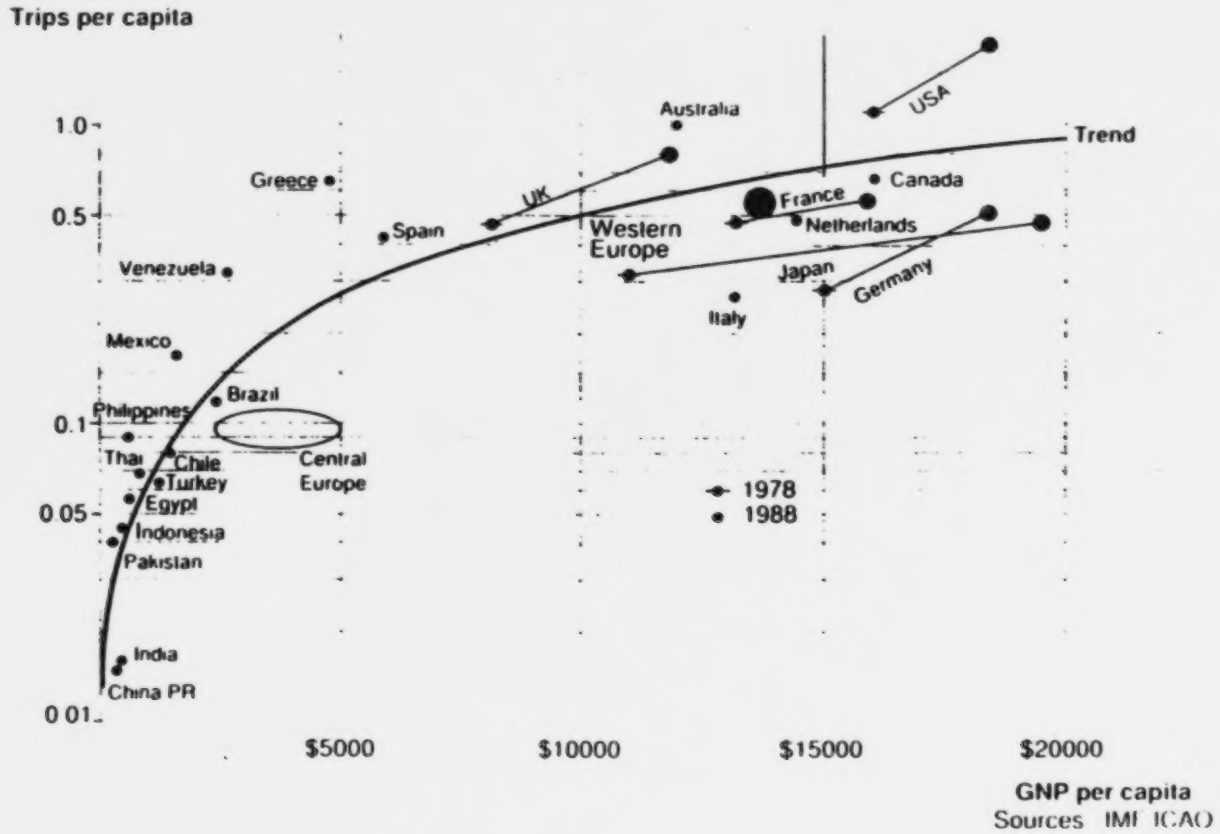
World Air Travel Forecast



SOURCE: BOEING

FIG. 4

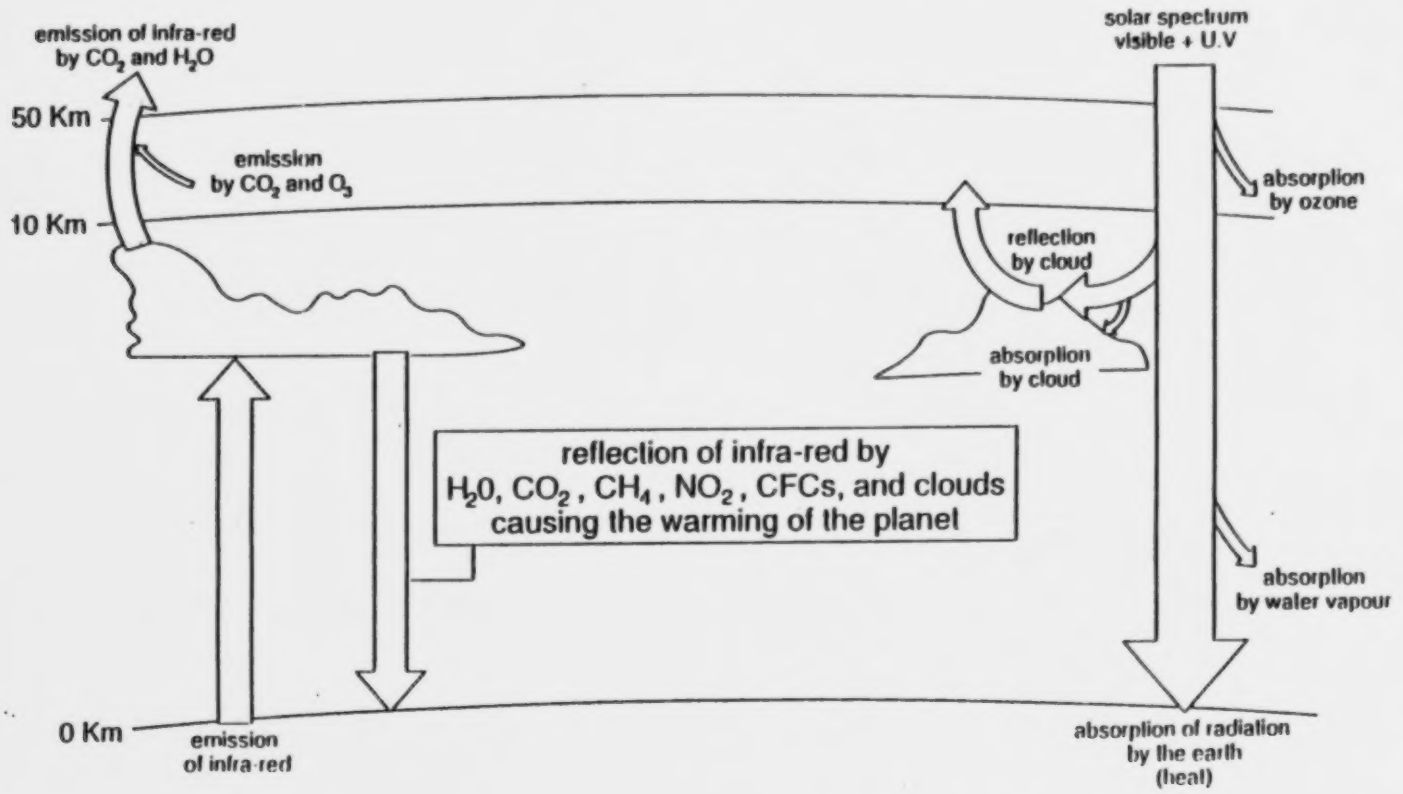
Trips per inhabitant of selected countries in relation to economic development



SOURCE: AIRBUS

FIG. 5

Greenhouse effect


emission of infra-red by CO_2 and H_2O
50 Km
10 Km
0 Km
emission by CO_2 and O_3
emission of infra-red
solar spectrum visible + U.V
absorption by ozone
reflection by cloud
absorption by cloud
reflection of infra-red by H_2O, CO_2, CH_4, NO_2, CFCs, and clouds causing the warming of the planet
absorption by water vapour
absorption of radiation by the earth (heat)

Source: CNRM

FIG. 6

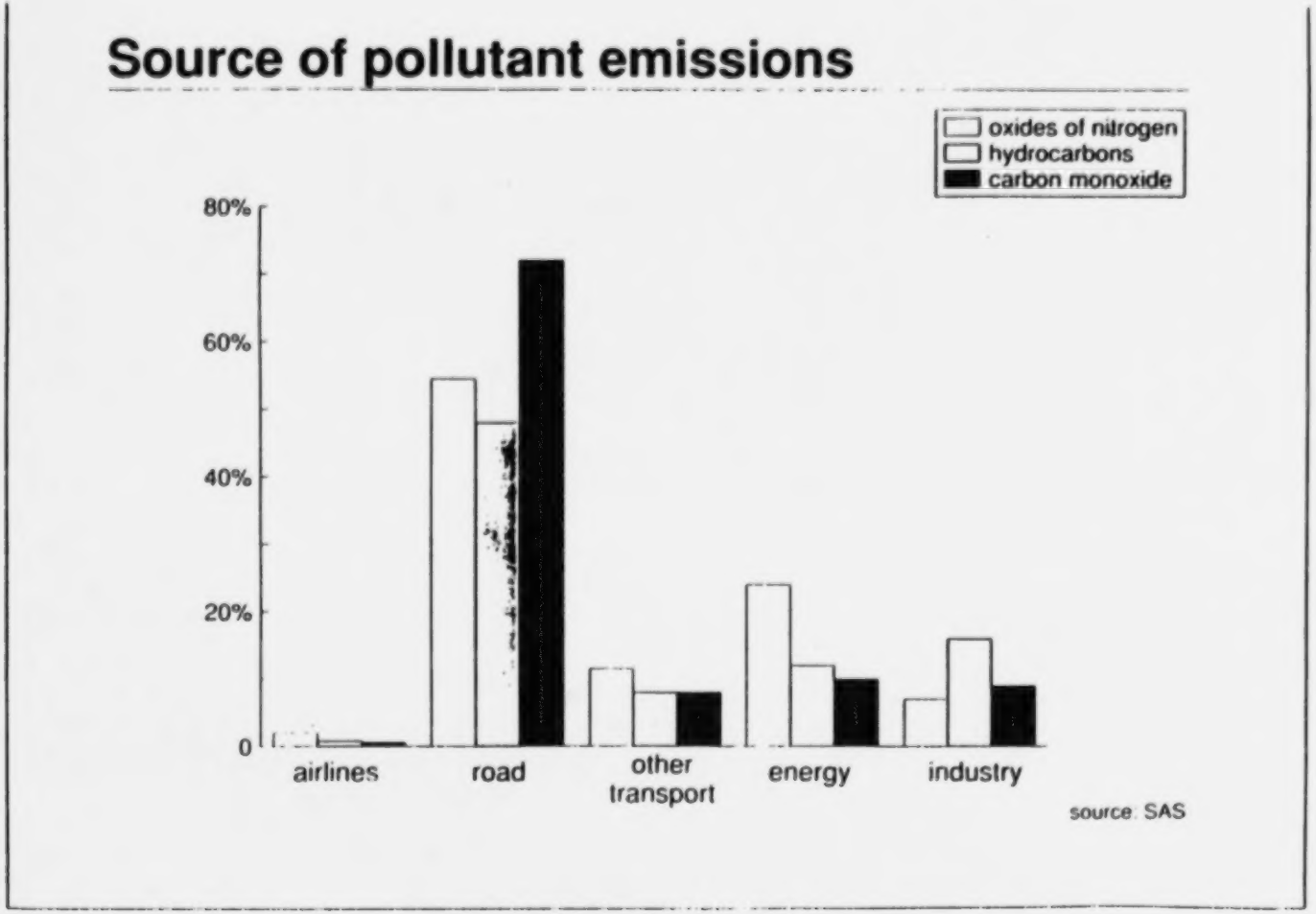
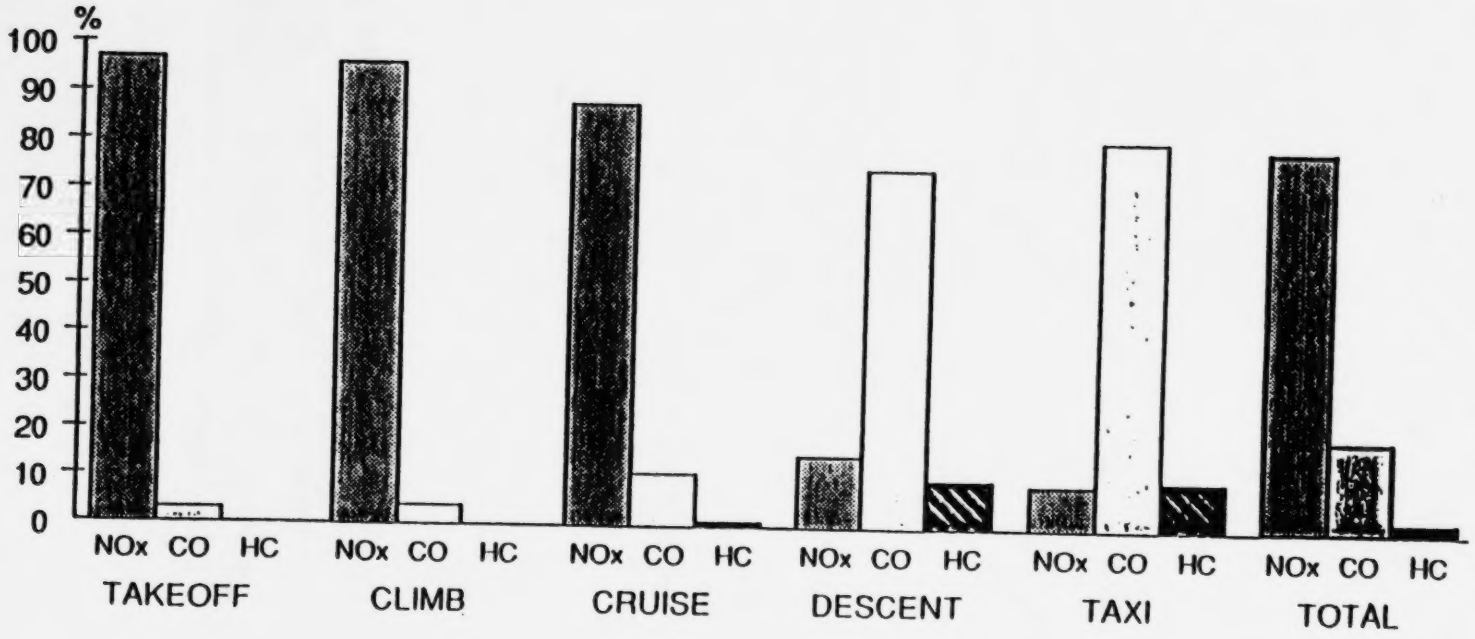

Source of pollutant emissions
oxides of nitrogen
hydrocarbons
carbon monoxide
80%
60%
40%
20%
0
airlines
road
other transport
energy
industry
source: SAS

FIG. 7

Emission Distribution By Pollutant (In Weight)



Typical 500 NM mission with CFM engines

SOURCE: CFMI

FIG. 8

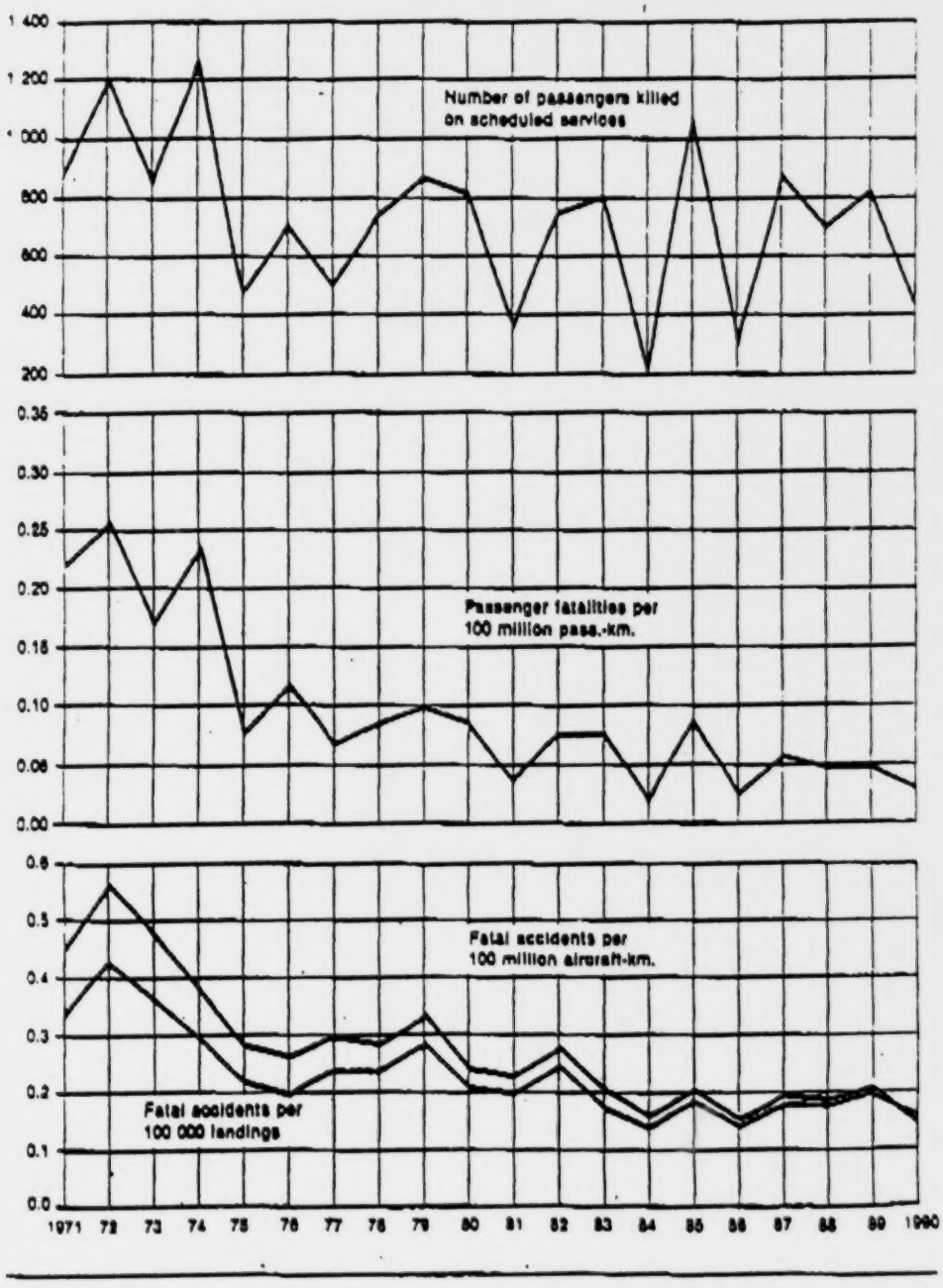
BRITISH AIRWAYS EMISSIONS TO THE ATMOSPHERE FROM WORLDWIDE FLYING OPERATIONS

	1,000 tonnes per year
Carbon dioxide	11,700
Water	4,600
Hydrocarbons	8
Carbon monoxide	18
Sulphur dioxide	22
Nitrogen oxides	not available

Estimates based on British Airways internal data

.. .. Fatal accident rates for passengers on world scheduled services, 1971-1990.

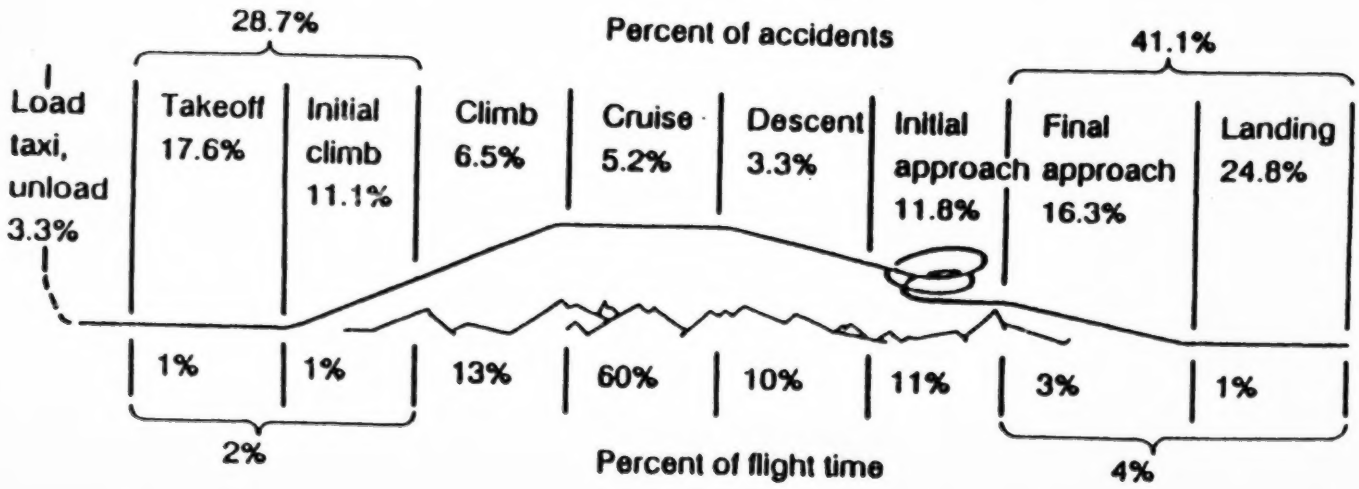
(Accident rates refer to traffic of ICAO Contracting States, excluding the USSR)



SOURCE: ICAO

FIG. 10

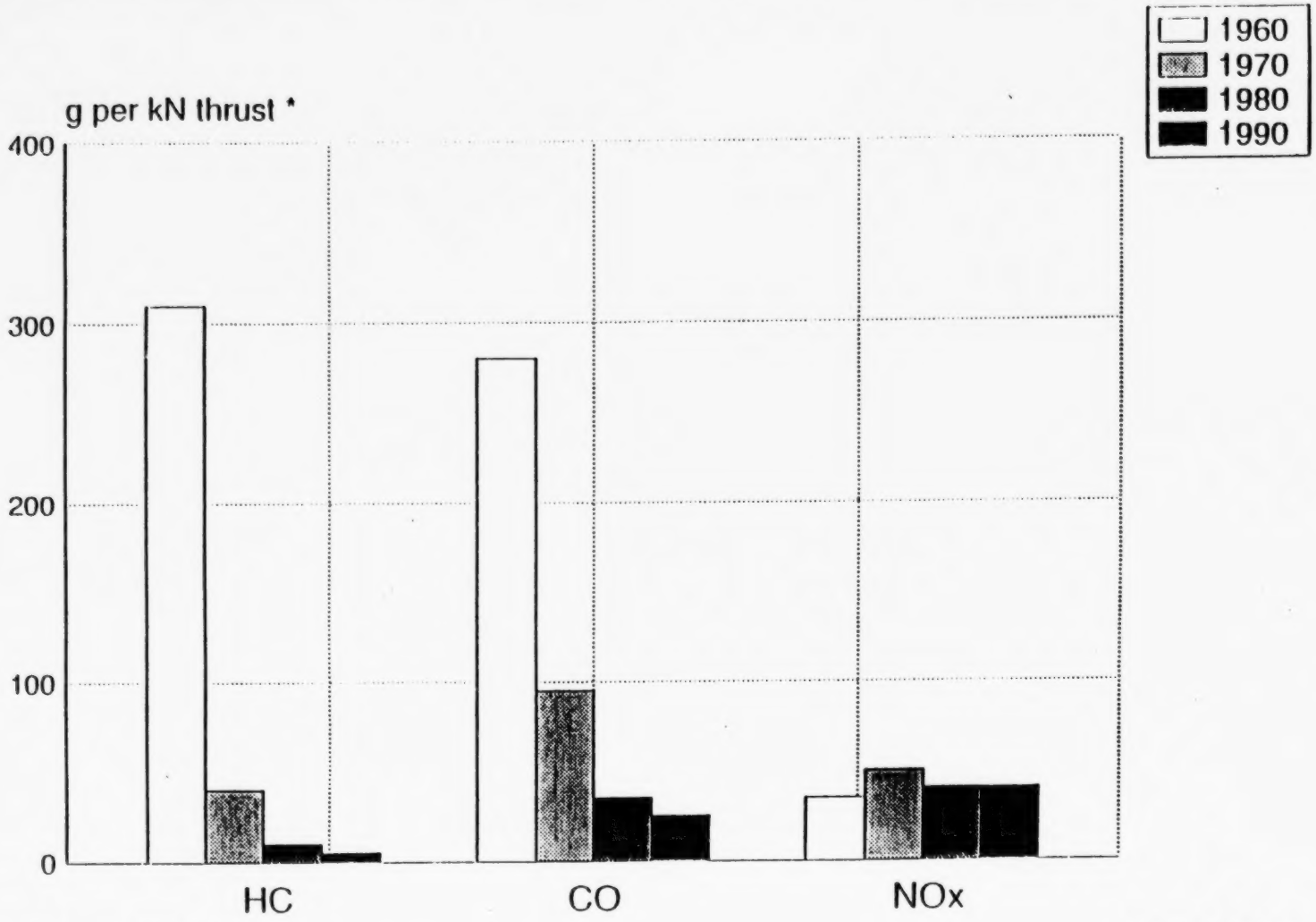
Aircraft accidents by flight mode



SOURCE: ROLLS-ROYCE

FIG. 11

Benefits of technology on emissions

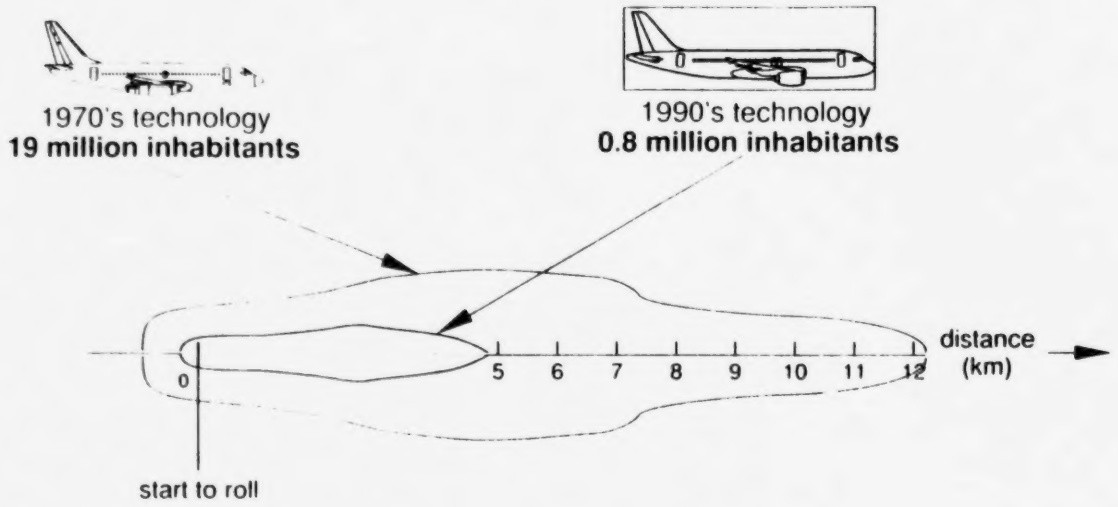


* based on standard ICAO LTO cycle

Source: ICAO

FIG. 12

Technology for a quieter environment

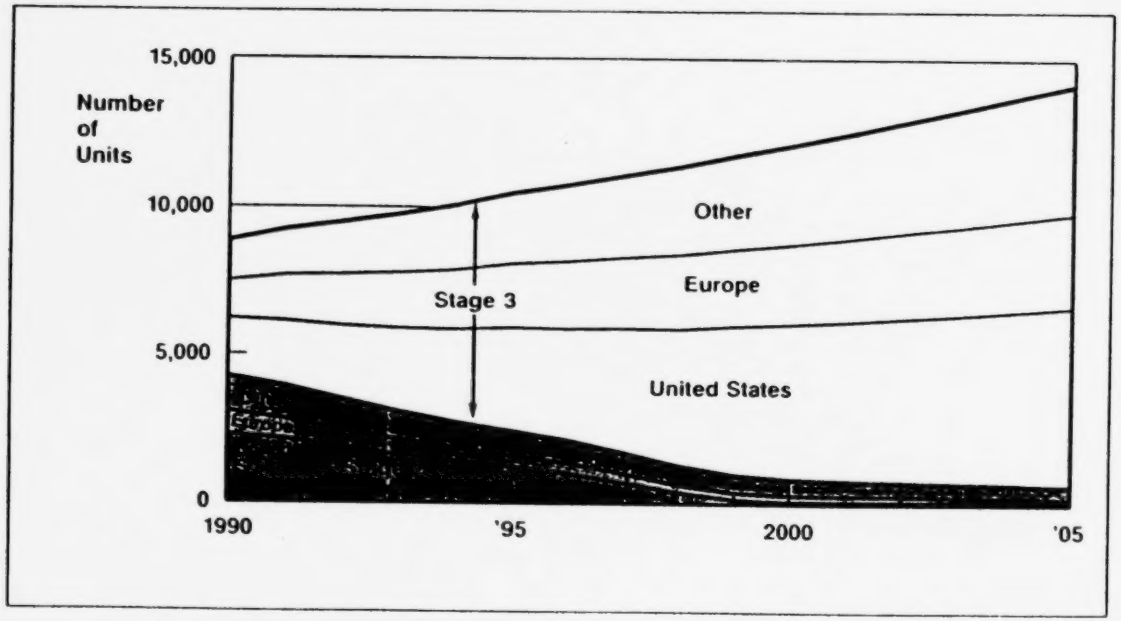


US and European population living within the 95 PNdb take-off noise contour

SOURCE: AIRBUS

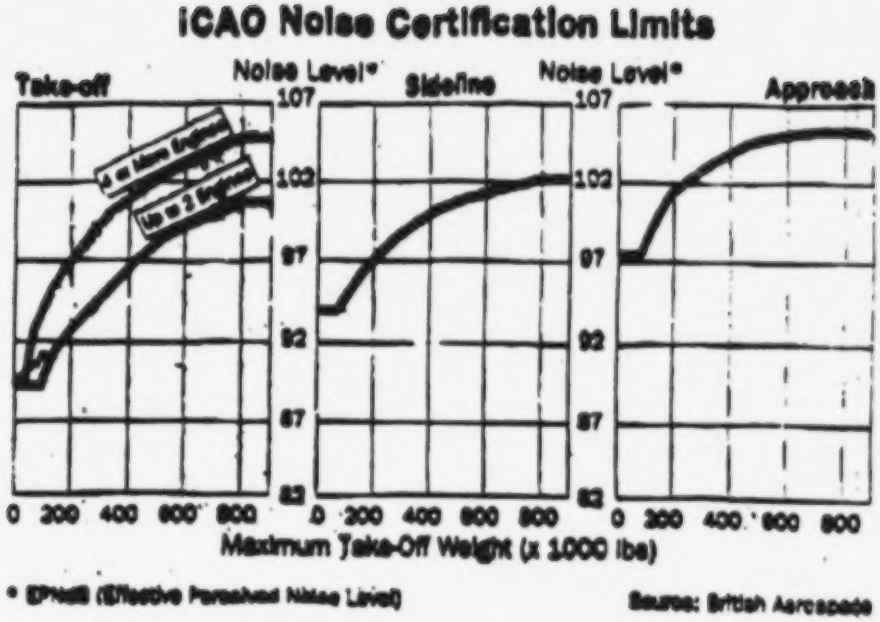
FIG. 13

World Stage 2 Versus Stage 3 Fleets



SOURCE: BOEING

FIG. 14


ICAO Noise Certification Limits
Take-off
Noise Level*
Sideline
Noise Level*
Approach
107
102
97
92
87
82
0 200 400 600 800
Maximum Take-Off Weight (x 1000 lbs)
* EPNdB (Effective Perceived Noise Level)
Source: British Aerospace